AXUV "self-calibration" procedure, transfer calibration procedure and results for diodes at U3c, 9/04

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I. Self-calibration.

Resources needed:
1. AXUV-100G diode(s) from IRD, with minimum 200 MΩ shunt resistance (average of current at ± 10 mV bias < 50 pA) and < 1 pA dark current
2. Rotary feedthrough with AXUV mount, capable of ±90° tilt from normal, with beam continuously aligned to a single spot on the SXUV surface
3. Beamlines x8a and u3c at NSLS, estimate 1-2 weeks at each beamline per diode, with calibrated electrometer(s) and noise-free environment.
4. CXRO and Rife transmission (attenuation length) data for Si, SiO$_2$, and C (see

    reference data.xls

    attached "reference data.xls" file)
5. Linear interpolation add-in functions are needed to support the reference data spreadsheet (Microsoft Excel) is to be used. These are available for free on the

    XlXtrFun.exe

    web and are included here as well (   ).
6. Software capable of nonlinear least squares (NLLS) fitting (error minimization) with 3 independent variables, 6 parameters, and up to 200 data points, with reporting of total RMS error and standard error for each parameter. SigmaPlot 8.0 is known to provide this functionality. A free web-based calculator is also

    NLLS.htm

    available: (   ).

Per-beamline procedure.

Day 1:
Carefully vent the endstation and remove the top flange. Replace it with the rotary mount and AXUV to be calibrated. Try to set the normal angle to a specific target value (a round number like 160° is good). If this is not available, try to at least estimate the normal angle by viewing through the window. Pump overnight. This is also an opportunity to install replacement diodes or perform other service on the top flange. (1/2 day)

<u>Day 2</u>:

Verify alignment of the detector and rotary feedthrough to the x-ray beam. First, the angle-resolved response curve must be measured to find the normal angle. One photon energy per beamline is sufficient for this test. The recommended photon energies to use are 575 eV on the U3c beamline and 5000 eV on X8a (these energies provide good signal level, angle contrast, and avoid any reflectivity artifacts which might be evident at high angles). The 1/16" diameter aperture should be used. At the test energy, scan the angle using the "back-and-forth" method, and measure the background signal before and after the angle data collection. Use the beamline software to average 10 readings at each angle. Once collected, fit the data, throwing away as many points at the edges as needed for a good symmetric fit around the normal angle (± 75° from normal should be reasonably achievable). For this fit, a complete NLLS fitter is not required, because the standard error is not needed. Only the normal angle estimate is needed, and this can be adequately found using the Excel "Solver" tool. To determine the number of points which need to be thrown out, increment the number of discarded points on each side and recording the RMS error. When throwing out more points no longer improves the fit, enough points have been discarded. Attached is an example data set and fit for the U3c

575 eV angle scan

beamline: ($^{AXUV100G02520.xls}$). This simple spreadsheet calculation is used to keep the data organized and reduce the raw current measurements into relative signals ($A_\theta = I_\theta/I_0$).

The normal angle needs only to be estimated within 1 degree precision.

The fitting functions to use are listed below (the attenuation lengths λ are given in the reference data spreadsheet as well as the appendix):

1. For low energy, $A(\theta) = \exp\left(-\dfrac{p1}{\lambda_{SiO_2}(E)} \cdot \left(\dfrac{1}{\cos(\theta - p2)} - 1\right)\right)$

The parameters are dead layer thickness (typically ~0.005 μm) and normal angle.

2. For high energy, $A(\theta) = \dfrac{1 - \dfrac{\exp\left(-\dfrac{p1}{\lambda_{Si}(E)\cos(\theta - p2)}\right)}{\left(\dfrac{p3}{\lambda_{Si}(E)\cos(\theta - p2)} + 1\right)}}{1 - \dfrac{\exp\left(-\dfrac{p1}{\lambda_{Si}(E)}\right)}{\left(\dfrac{p3}{\lambda_{Si}(E)} + 1\right)}}$

The parameters are active layer thickness (typically ~25 μm), normal angle, and diffusion length (MS previously measured ~10.7 μm).

At this step, the parameter values are not important except the normal angle. Use this angle for all subsequent steps.

Next, check the horizontal alignment of the beam with respect to the AXUV rotation axis. To accomplish this, the x-ray beam must be able to translate horizontally with respect to each the detector (or visa versa). On U3c (or X8a using multilayers), the x-ray beam striking the aperture plate is roughly 5 mm wide. This allows the user to move the beam across the detector by simply moving the aperture plate (on X8a the alignment for Si crystal dispersion can be achieved by translating the endstation horizontally to center the beam on the aperture plate position found for the multilayers). The 1/16" diameter aperture should again be used (was verified to give identical selfcal data, with better repeatability and SNR, compared with smaller aperture sizes). To test for alignment, scan the beam across the detector and record the edge positions (50% rise / drop points) with the AXUV at normal and $\pm 80°$. Verify that the edges at normal are well outside the edges at $\pm 80°$. Also, verify that the effective beam width is the same at $+ 80°$ as with $- 80°$. Finally, take the average of the edge positions for $+$ and $- 80°$ as the center position. This should be done at 4 energies per beamline (2 per dispersion medium) to verify that the optical alignment is the same for the entire range of operating conditions. It is recommended to always go in the same (+) direction when setting the aperture plate position, as there may be a small but significant backlash in the mechanism. Attached is a worksheet for collecting and reviewing such data for U3c

(align test 60 eV
AXUV100G02520.xls).

Recommend test energies for angle scans and alignment verification are listed in the table below:

Alignment Verification Energies

PE (eV)	XTAL	FILTER1	FILTER2	HOT
60	G1	Al 0.38	Al 0.38	Si 5
210	G1	open	C 1	Rh 4
310	G2	Ti 0.33	open	V 2.5
575	G2	open	Fe 0.53	open
1200	ML	Mg 10	open	open
1750	ML	Si 15	open	open
3000	Si	Mg 10	open	open
5800	Si	Mg 10	open	open

These energies are chosen to provide two disparate energies on each dispersion element.

It should be possible to accomplish both of these alignment tests with 1 day at a single beamline.

Day 3:

Collect and fit the A60 data. Attached is an example worksheet for doing this.

(selfcal A60 data AXUV100G02520.xls). At each energy (see Appendix), the back-and-forth method is used to measure the ratio of signal at 60 degrees tilt with respect to normal (as measured in the alignment step). The ring current and background level is also recorded, and used to generate the experimental A60 values. The beamline calibration software is used to average 10 measurements at each step.

A rough fit should be obtained with the complete model. This is also provided in the worksheet, along with graphical feedback. Once reasonable starting guesses for the parameters have been obtained (and any unnecessary parameters removed), the fit should be moved to a NLLS fitting procedure to find standard RMS and parameter errors. Keep in mind that the function has the three material x-ray absorption lengths as its three independent variables (x1, x2, x3) for the NLLS fitting. Each is looked up based on the photon energy value.

The model is given below [$A_{60}(x1(E), x2(E), x3(E))$ is abbreviated $A_{60}(E)$]:

$$A_{60}(E) = \frac{\exp\left(-\dfrac{2p1}{\lambda_{SiO_2}(E)} - \dfrac{2p2}{\lambda_C(E)} - \dfrac{2p3}{\lambda_{Si}(E)}\right) \cdot \left(1 - \dfrac{\exp\left(-\dfrac{2p5}{\lambda_{Si}(E)}\right)}{\left(\dfrac{2p6}{\lambda_{Si}(E)} + 1\right)}\right) + p4 \cdot \exp\left(-\dfrac{2p2}{\lambda_C(E)} - \dfrac{2p1}{\lambda_{SiO_2}(E)}\right) \cdot \left(1 - \exp\left(-\dfrac{2p3}{\lambda_{Si}(E)}\right)\right)}{\exp\left(-\dfrac{p1}{\lambda_{SiO_2}(E)} - \dfrac{p2}{\lambda_C(E)} - \dfrac{p3}{\lambda_{Si}(E)}\right) \cdot \left(1 - \dfrac{\exp\left(-\dfrac{p5}{\lambda_{Si}(E)}\right)}{\left(\dfrac{p6}{\lambda_{Si}(E)} + 1\right)}\right) + p4 \cdot \exp\left(-\dfrac{p2}{\lambda_C(E)} - \dfrac{p1}{\lambda_{SiO_2}(E)}\right) \cdot \left(1 - \exp\left(-\dfrac{p3}{\lambda_{Si}(E)}\right)\right)}$$

The parameters and their common symbols are: the thickness of oxide (t_{do}), carbon (t_{dc}), and silicon (t_{ds}) dead layers, probability of charge migration into the active layer from the dead layer (s_s), thickness of the active layer (t_s), and diffusion length for charge migrating from below the active layer (L). For active layer thickness in the range of 20-50 μm (as is seen on IRD diodes), there is a convenient simplification in the model for the two beamlines, which operate above or below 1000 eV. That is, below 1000 eV, the silicon absorption length is much smaller than the active area thickness which makes the measurement insensitive to the t_s and L parameters. Likewise, above 1000 eV, the attenuation of responsivity due to surface dead layers is very small. In addition, it is worth checking for the importance of t_{ds} and s_s to the fit quality. If the standard error on either of these parameters approaches or exceeds the value of the parameter itself, it is likely that one or both may not be required in the model. The automatic optimization algorithm may also need parameter values to be constrained in order to converge, and to provide meaningful results (all of these values should be non-negative, and s_s must be no greater than unity).

Once the data is reasonably fit, the model, parameters, RMS error and parameter standard errors must be recorded. These will be used to generate standard detector response file

and corresponding error bars. An example recorded fit is attached here

NLLS fit example.pdf

(   ).

This should take 1 day (½ day for data collection plus ½ day for data analysis).

Day 4:
The standard end station top flange must be replaced to the beamline and pumped overnight. Some re-plumbing and alignment may also be necessary to restore the beamline to normal operations. Since the top flange may take a while to pump after having been on the bench for at least 3 days, the pumping should start as early as possible. Assuming all the alignment tests and fits so far are reasonable, all of the data collection should be complete by this point, and the endstation can be put back together and started pumping.

The final step in the self-calibration is the generation of a standard response file. Due to the spline interpolation used by the beamline calibration software, it is highly recommended to use the same energy grid as used in previous response files; it contains higher density of points near the material edges, where the responsivity changes rapidly. The file below provides the standard list of energies, as well as the response file format which is required for use with the LabVIEW calibration software (note the end-of-line characters must be preserved and are not DOS/Windows standard). A LabVIEW program is also attached which creates the file with the proper format (file path, tab-delimited data and header text are copied into the text boxes).

Si AXUV-100 #2,   Create monitor file.vi
f.rsp

The errors listed for the responsivity at each energy are calculated from the standard errors for each parameter. Since the charge-pair creation energy (w = 3.70 ± 0.07 eV) also has an error associated with it, the resulting error includes this (p7 ≡ w). Below are shown the formulae for responsivity (S) and overall relative error (RE) which are listed in the response file.

$$S(E, p1, p2, p3, p4, p5, p6, p7) = \frac{1}{p7}\left(\exp\left(-\frac{p1}{\lambda_{SiO_2}(E)} - \frac{p2}{\lambda_C(E)} - \frac{p3}{\lambda_{Si}(E)}\right) \cdot \left(1 - \frac{\exp\left(-\frac{p5}{\lambda_{Si}(E)}\right)}{\left(\frac{p6}{\lambda_{Si}(E)}+1\right)}\right) + p4 \cdot \exp\left(-\frac{p2}{\lambda_C(E)} - \frac{p1}{\lambda_{SiO_2}(E)}\right) \cdot \left(1 - \exp\left(-\frac{p3}{\lambda_{Si}(E)}\right)\right) \right)$$

$$RE_1(E) = 1 - \frac{S(E, p1 + \Delta p1, p2, p3, p4, p5, p6, p7)}{S(E, p1, p2, p3, p4, p5, p6, p7)}$$

$$RE_2(E) = 1 - \frac{S(E, p1, p2 + \Delta p2, p3, p4, p5, p6, p7)}{S(E, p1, p2, p3, p4, p5, p6, p7)}$$

etc.

$$RE(E) = \sqrt{\sum_{i=1}^{7} (RE_i(E))^2}$$

The response listed in the file is the model value. The error bars listed are quadrature sums of each standard parameter error at each energy.

Errors in the standard diode file are 1-sigma values. The results of calibration of diode or filter (response file output of the LabVIEW calibration software) is 2-sigma value (twice the quadrature sum of detector error and statistical error).

Day 5:
The uniformity of this response over the surface of the AXUV diode can also have an impact on the errors listed in this file. Earlier work took 2/3 times the total variation seen among measurements at 0, ± 2.1, and ± 4.2 mm vertical offset at each energy (using a "reasonable" experimental energy grid interpolated into the standard diode grid). This can also be accomplished using the standard deviation of the responses at the five positions (one rotation of monitor diode stalk is ~ 2.1 mm vertical offset).

Although the rotary feedthrough cannot be translated, the uniformity of the standard diode can be measured once it is mounted on an n-connector, using the detector stalk. It can also be measured for the monitor diode. Once the uniformity error is measured, it is added in quadrature with the other known errors. It does not affect the self-calibration value itself.

II. Transfer Calibration of Installed Monitor Diode.

Resources needed:
7. AXUV-100G diode(s) from IRD, with minimum 200 MΩ shunt resistance (average of current at ± 10 mV bias < 50 pA) and < 1 pA dark current, installed to the beamline standard endstation.
8. Self-calibrated reference AXUV-100G diode(s) from IRD with trusted dataset, minimum 200 MΩ shunt resistance and < 1 pA dark current, on n-connector mount.
9. Beamlines x8a and u3c at NSLS, estimate 2-3 days at each beamline per diode, with calibrated electrometer(s) and noise-free environment.
10. CXRO and Rife transmission (attenuation length) data for Si, SiO_2, and C (see

reference data.xls

attached "reference data.xls" file)

11. Linear interpolation add-in functions are needed to support the reference data spreadsheet (Microsoft Excel) is to be used. These are available for free on the

XIXtrFun.exe

web and are included here as well (   ).
12. Software capable of nonlinear least squares (NLLS) fitting (error minimization) with 3 independent variables, 6 parameters, and up to 200 data points, with reporting of total RMS error and standard error for each parameter. SigmaPlot 8.0 is known to provide this functionality. A free web-based calculator is also

NLLS.htm

available: (   ).

Per-beamline procedure.

Day 1:
Install the standard diode on its n-connector to the detector stalk and pump down.

Measure the vertical centering of the standard diode by noting the rise and fall of the detector signal with respect to the vertical stalk position. Set the diode vertical position to center.

Perform energy scans at reasonably dense energy spacing (e.g. 50-150 eV @ 2 eV & 155-250 eV @ 5 eV on G1, 250-330 eV @ 5 eV, 340-590 eV @ 10 eV, 600-1000 eV @ 25 eV on G2). Use 10 second settling time, 10 readings per point, 700 ms reading interval, detector calibration, unit normalization. You might want to perform each scan twice in order to identify bogus values.

Day 2:
Fit the data with the full model. The monitor diode responsivity measured is the reference diode responsivity divided by the unit normalization value given in the response file from the energy scans.

A rough fit should be obtained with the complete model and check with graphical

Si AXUV-100 #2,
f.rsp

feedback. This can be performed on the standard reference diode grid (   ).
At each energy, the attenuation length needs to be looked up from the reference data sheets. Example fit is shown in the attached worksheet

transfer cal
example.xls

Once reasonable starting guesses for the parameters have been obtained (and any unnecessary parameters removed), the fit should be moved to a NLLS fitting procedure to find standard RMS and parameter errors (interpolated to the self-cal grid listed in the appendix). Keep in mind that the function has the three material x-ray absorption lengths as its three independent variables (x1, x2, x3) for the NLLS fitting. Each is looked up based on the photon energy value.

The model is given below [S(x1(E), x2(E), x3(E)) is abbreviated S(E)]:

$$S(E) = \frac{1}{p7}\left(\exp\left(-\frac{p1}{\lambda_{SiO_2}(E)} - \frac{p2}{\lambda_C(E)} - \frac{p3}{\lambda_{Si}(E)}\right)\cdot\left(1 - \frac{\exp\left(-\frac{p5}{\lambda_{Si}(E)}\right)}{\left(\frac{p6}{\lambda_{Si}(E)} + 1\right)}\right) + p4\cdot\exp\left(-\frac{p2}{\lambda_C(E)} - \frac{p1}{\lambda_{SiO_2}(E)}\right)\cdot\left(1 - \exp\left(-\frac{p3}{\lambda_{Si}(E)}\right)\right)\right)$$

The parameters and their common symbols are: the thickness of oxide (t_{do}), carbon (t_{dc}), and silicon (t_{ds}) dead layers, probability of charge migration into the active layer from the dead layer (s_s), thickness of the active layer (t_s), diffusion length for charge migrating from below the active layer (L), and average charge-pair creation energy (w).

For active layer thickness in the range of 20-50 μm (as is seen on IRD diodes), there is a convenient simplification in the model for the two beamlines, which operate above or below 1000 eV. That is, below 1000 eV, the silicon absorption length is much smaller than the active area thickness which makes the measurement insensitive to the t_s and L parameters. Likewise, above 1000 eV, the attenuation of responsivity due to surface dead layers is very small. In addition, it is worth checking for the importance of t_{ds} and s_s to the fit quality. If the standard error on either of these parameters approaches or exceeds the value of the parameter itself, it is likely that one or both may not be required in the model. The automatic optimization algorithm may also need parameter values to be constrained in order to converge, and to provide meaningful results (all of these values should be non-negative, and s_s must be no greater than unity).

Once the data is reasonably fit, the model, parameters, RMS error and parameter standard errors must be recorded. These will be used to generate standard detector response file and corresponding error bars. An example recorded fit is attached here

NLLS fit example 2.pdf

( ).

Note that the charge-pair creation energy parameter w is no longer fixed. This is in contrast with the self-calibration method, which is based on relative response measurements and relies on this value as a well-defined constant (which comes from other absolute calibration methods). Now that we are attempting to measure responsivity directly, the parameter is free. However, it should be constrained within the range of acceptable known values (i.e., 3.70 ± 0.07 eV implies the acceptable range of 3.63-3.77 eV).

The final step in the self-calibration is the generation of a standard response file. Due to the spline interpolation used by the beamline calibration software, it is highly recommended to use the same energy grid as used in previous response files; it contains higher density of points near the material edges, where the responsivity changes rapidly. The file below provides the standard list of energies, as well as the response file format which is required for use with the LabVIEW calibration software (note the end-of-line characters must be preserved and are not DOS/Windows standard). A LabVIEW program is also attached which creates the file with the proper format (file path, tab-delimited data and header text are copied into the text boxes).

Si AXUV-100 #2, Create monitor file.vi
f.rsp

The errors listed for the responsivity at each energy are calculated from the standard errors for each parameter. Since the charge-pair creation energy (w = 3.70 ± 0.07 eV) also has an error associated with it, the resulting error includes this (p7 ≡ w). Below are shown the formulae for responsivity (S) and overall relative error (RE) which are listed in the response file.

$$S(E, p1, p2, p3, p4, p5, p6, p7) = \frac{1}{p7}\left[\exp\left(-\frac{p1}{\lambda_{SiO_2}(E)} - \frac{p2}{\lambda_C(E)} - \frac{p3}{\lambda_{Si}(E)}\right) \cdot \left(1 - \frac{\exp\left(-\frac{p5}{\lambda_{Si}(E)}\right)}{\left(\frac{p6}{\lambda_{Si}(E)} + 1\right)}\right) + p4 \cdot \exp\left(-\frac{p2}{\lambda_C(E)} - \frac{p1}{\lambda_{SiO_2}(E)}\right) \cdot \left(1 - \exp\left(-\frac{p3}{\lambda_{Si}(E)}\right)\right)\right]$$

$$RE_1(E) = 1 - \frac{S(E, p1 + \Delta p1, p2, p3, p4, p5, p6, p7)}{S(E, p1, p2, p3, p4, p5, p6, p7)}$$

$$RE_2(E) = 1 - \frac{S(E, p1, p2 + \Delta p2, p3, p4, p5, p6, p7)}{S(E, p1, p2, p3, p4, p5, p6, p7}$$

etc.

$$RE(E) = \sqrt{\sum_{i=1}^{7}\left(RE_i(E)\right)^2}$$

The response listed in the new monitor response file is the model value. The error bars listed in this file are quadrature sums of the overall standard parameter error and the source calibration error at each energy. As available, uniformity errors from from source and current diode should also be folded into this quadrature sum.

The uniformity of this response over the surface of the AXUV diode can also have an impact on the errors listed in this file. Earlier work took 2/3 times the total variation seen among measurements at 0, ± 2.1, and ± 4.2 mm vertical offset at each energy (using a "reasonable" experimental energy grid interpolated into the standard diode grid). This can also be accomplished using the standard deviation of the responses at the five positions (one rotation of monitor diode stalk is ~ 2.1 mm vertical offset).

Errors in the standard diode file are 1-sigma values. The results of calibration of diode or filter (response file output of the LabVIEW calibration software) is 2-sigma value (twice the quadrature sum of detector error and statistical error).

Fitting the data and preparing the standard response file should take 1 day.
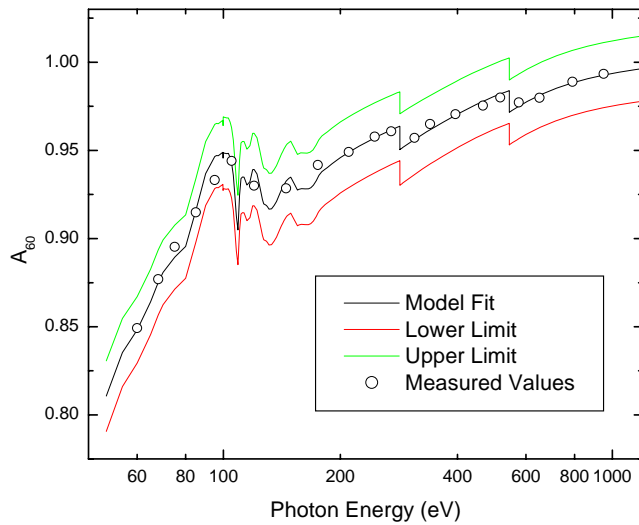
III. Results (September 2004).

The specific results for self-calibration of reference diode AXUV 02-5 #20 and transfer to AXUV 02-2 #15 (installed to U3c) are given below.

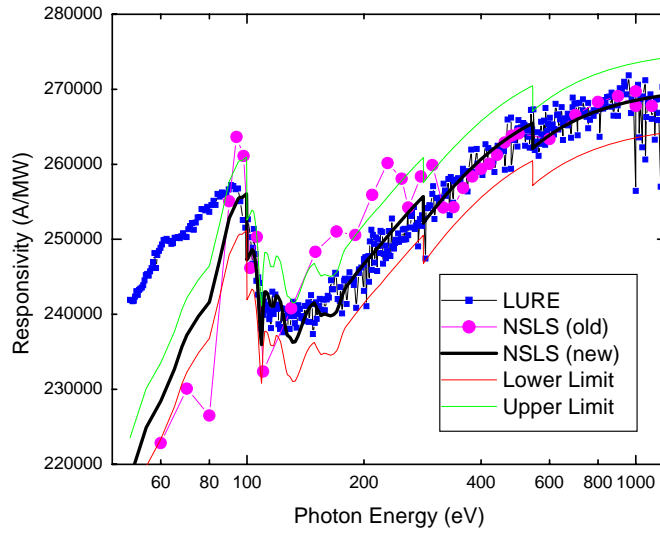**1. Self-calibration data and fit for AXUV 02-5 #20 (A60 vs. photon energy)**
RMS error of the fit: 2.1%, max error 1.4 %
Model parameters:
$t_{do} = 5.32 \pm 0.28$ nm, $t_{dc} = 1.24 \pm 0.57$ nm, $t_{ds} = 107 \pm 25$ nm, $s_s = 0.947 \pm 0.011$

2. Self-calibration data result for AXUV 02-5 #20 compared with previous results
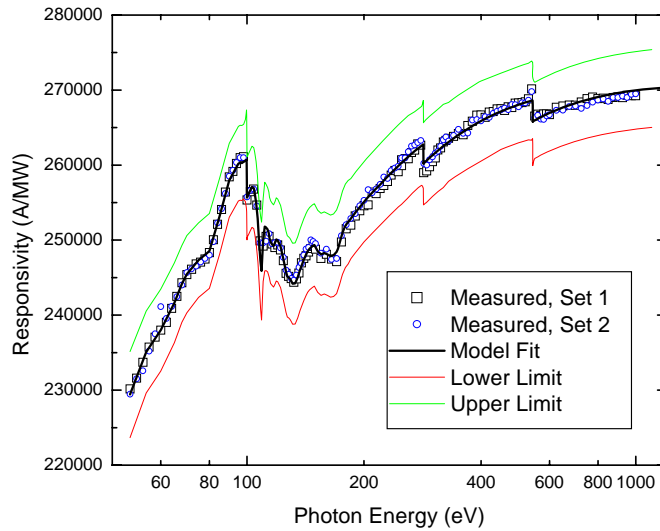

3. Transfer calibration data and fit for AXUV 02-2 #15

Average error of the fit: 2.1%, max error: 2.7 %

Model parameters:

$t_{do} = 4.440 \pm 0.042$ nm, $t_{dc} = 0.873 \pm 0.063$ nm,

$t_{ds} = 1.377 \pm 0.028$ nm, $s_s \equiv 0.0$, $w = 3.6891 \pm 0.0013$ eV

4. Verification of calibration data for AXUV 02-2 #15 with XRD 34

Notes:

A. Deviation below C K edge, trend agrees with LURE AXUV 02-5 #20 comparison data.

B. Deviation at 300 eV may result from improved shunt resistance (from 2 MΩ to > 200 MΩ in going from old AXUV-100 92-2 "#2" diode to new AXUV-100G 02-2 #15 diode)

C. Deviation from 100-500 eV agrees with historical observations of fluctuations of AXUV-100 "#2" diode from run to run
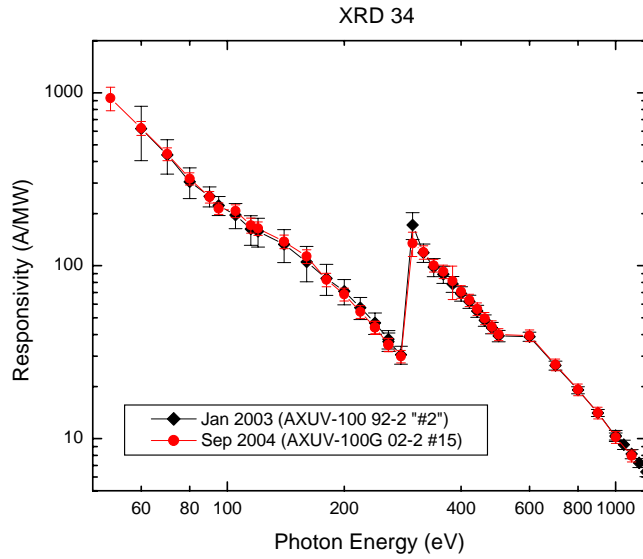
Appendix.

For reference, the optical constants (attenuation lengths λ) for each of the three relevant materials (silicon dioxide, silicon, and carbon) and the beamline filtering configuration is listed at each of the self-cal energies in the table below. The optical data is repeated in the reference data spreadsheet.

The energies are chosen to provide sensitivity to all relevant material edges (use two points on each side of each edge), span the normal operating range of the beamline, and to avoid operating points of the beamline where the photon flux is low or optical transition (filter or HOT) is nearby.

ALL SELF-CAL POINTS

PE (eV)	XTAL	FILTER1	FILTER2	HOT	lambda_Si (µm)	lambda_SiO2 (µm)	lambda_C (µm)
60	G1	Al 0.38	Al 0.38	Si 5	0.34971	0.03964	0.06180
68	G1	Al 0.38	Al 0.38	Si 5	0.34474	0.04956	0.08000
75	G1	Si 0.5	Si 0.5	Si 5	0.41834	0.05585	0.09850
85	G1	Si 0.5	Si 0.5	Nb 10	0.59122	0.07519	0.12849
95	G1	Si 0.5	Si 0.5	Rh 10	0.57629	0.13366	0.16273
105	G1	Be 0.4	open	Rh 10	0.07750	0.12608	0.20127
120	G1	open	Ti/B 0.03/1	Rh 10	0.04215	0.09830	0.26726
145	G1	open	Ti/B 0.03/1	Rh 10	0.04409	0.08533	0.40513
175	G1	Ti/B 0.03/1	Ti/B 0.03/1	Rh 4	0.05005	0.08913	0.62179
210	G1	open	C 1	Rh 4	0.06878	0.12681	0.99905
245	G1	open	C 1	V 2.5	0.08941	0.16969	1.50321
270	G2	C 2	open	V 2.5	0.10819	0.20689	2.06992
310	G2	Ti 0.33	open	V 2.5	0.14290	0.27604	0.10387
340	G2	Ti 0.33	open	V 2.5	0.17326	0.33658	0.12752
395	G2	open	Ti 0.6	V 2.5	0.24255	0.47384	0.17990
465	G2	open	Fe 0.53	Cu 2.2	0.35877	0.70338	0.26953
515	G2	open	Fe 0.53	Cu 2.2	0.46356	0.90938	0.34818
575	G2	open	Fe 0.53	open	0.61122	0.34513	0.46004
650	G2	Fe 0.53	Fe 0.53	open	0.84492	0.46822	0.62716
790	G2	Ni 0.75	open	open	1.39055	0.76330	1.04343
950	G2	Al 6.4	open	open	2.30585	1.23324	1.73147
1050	ML	Mg 10	open	open	3.08932	1.61702	2.28561
1200	ML	Mg 10	open	open	4.45017	2.31243	3.33267
1420	ML	Al 10.2	open	open	6.97650	3.63572	5.39792
1630	ML	Si 15	open	open	10.19722	5.30897	8.04922
1750	ML	Si 15	open	open	12.44250	6.46493	9.89501
1930	ML	Pt 0.75	open	open	1.42232	2.49392	13.18587
2150	Si	Mg 10	open	open	1.84806	3.27016	18.11369
3000	Si	Mg 10	open	open	4.38342	7.90370	48.93125
4000	Si	Mg 10	open	open	9.62547	17.57131	117.40677
5000	Si	Mg 10	open	open	18.01855	33.20214	234.33859
5800	Si	Mg 10	open	open	27.51142	50.98887	373.12121